A TECHNIQUE FOR ACCURATE RECONSTRUCTION OF INTERNAL STRUCTURES OF MICROMORPHIC FOSSILS

by P. G. BAKER

ABSTRACT. The problems involved in the skewed reconstruction of structures of serially sectioned specimens are discussed. It is concluded that the deficiency of existing models, when applied to micromorphic specimens, lies in the fact that no consideration is given to the need to modify the x co-ordinates in skewed grids. A new, mathematically constructed, skewed model is proposed, which eliminates distortion in the x, y plane.

VARIOUS techniques for reconstruction of structures from serial sections have been used for a number of years, either using traces made on wax or plastic sheets of appropriate thickness (Sollas and Sollas 1913; St. Joseph 1937) or producing simple graphic reconstructions (Muir-Wood 1934; Ovcharenko 1967). The inadequacy of reconstructions of the type made by Muir-Wood was recognized by Ager (1956) who appreciated that the most informative orientation is that which depicts the specimen in a semi-profile position, i.e. rotated slightly and tilted towards the observer. To achieve this effect, Ager used the technique of plotting peel traces on to skewed grids in order to enhance the three-dimensional appearance of the reconstructed structure. Ager noted that even using this technique, some salient features would remain hidden. Westbroek (1967) and Baker (1971, 1972) largely overcame this problem by partially 'exploding' their reconstructions. However, although comment such as 'the amount of skew must of course vary according to the structures it is required to present' (Ager 1963, p. 223) is common in the literature, reconstructions of internal structures based on skewed grids almost always lack precise detail of the way in which the skewness is produced and, undoubtedly, the amount of skew in many published reconstructions has been calculated intuitively. The lack of works specially devoted to the techniques of making reconstructions was noted and to some extent remedied by Kats, Popov, and Tkhorzhevskiy (1973). A fundamental problem, remaining unsolved by Kats *et al.* (1973, fig. 5) model is that rotating and tilting a specimen relative to an observer, produces an apparent foreshortening of the x, y, and z axes (text-fig. 1A–D). In order to maintain the correct geometric perspective of the reconstruction this foreshortening must be incorporated into the reconstruction framework. The inadequacy of the majority of previous models (Ager 1963; Kats *et al.* 1973) is due to the fact that the authors had overlooked the need to modify the ratios of the x, y, and/or z co-ordinates on the skewed grid, the inevitable result of this omission being distortion of the reconstructed specimen (text-fig. 1E, F). Where the specimen is large or the magnification small and where the structure being investigated can be seen in relation to the whole shell this distortion, apart from considerations of an aesthetic nature, is probably of little consequence. However, where the shell and the internal structures

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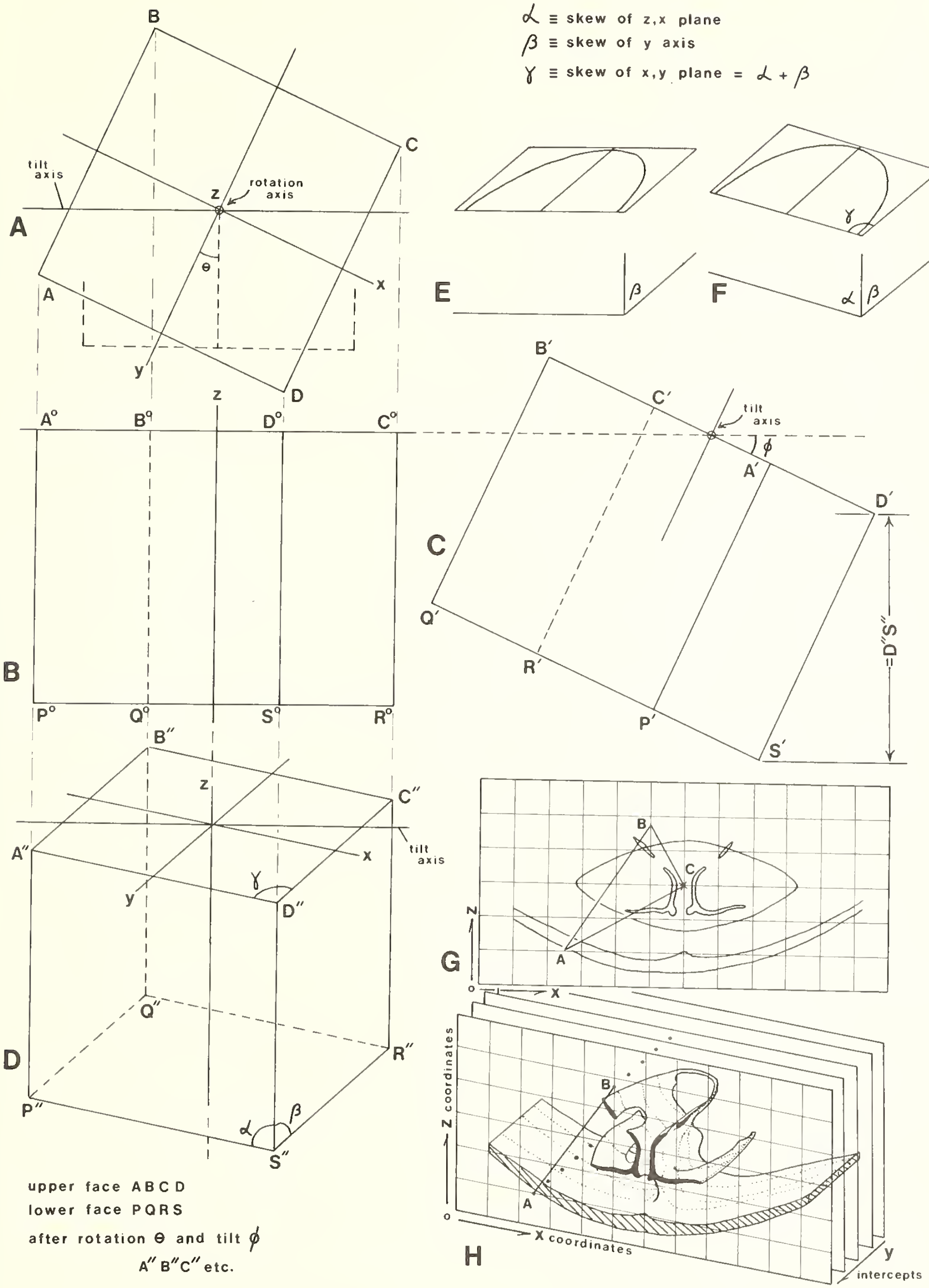
being investigated are very small, microprojection of sections is necessary, at a magnification at which the field of view usually encompasses only part of a structure. In this case the need for accuracy of superimposition of sections becomes critical. A very high degree of accuracy is necessary because it is essential to be able to recognize changes in the relative position of parts of a structure, both with regard to the shell and to each other, through successive sections. It is considered that the deficiency in existing models may be rectified by description of a technique, initially developed (Baker 1972) for the study of early loop development of juvenile zeilleriid brachiopods. The technique described is equally applicable to any micromorphic specimens.

Preparation of the material. In order to determine the internal structure of zeilleriid juveniles selected specimens were mounted at the required orientation in blocks of cold setting resin and serially ground on a parallel grinder at 0·02 mm intervals. Each ground surface was polished, etched, and replicated using cellulose acetate. The techniques used in the production of cellulose acetate peels are now so well known (Kummel and Raup 1963) that it is not considered necessary to describe them further. In view of the need for a very high degree of accuracy of peel superimposition, a technique has been devised in which the inherent error is not likely to exceed 1%. Reference points *A* and *B* are marked on the block with a specially sharpened needle prior to taking the cellulose acetate peels, care being taken to ensure frequent re-marking so that the reference points are not ground away during sectioning.

Superimposition of the microprojected peels. Each peel is mounted, preferably, with one axis of the specimen vertical and the point to be enlarged (*C*) centred in a position (text-fig. 1G) which will ensure its appearance in the field of view at high magnification. The peel is projected on to a squared grid (large enough to accommodate the ultimate magnification) at a magnification (e.g. × 10) which enables the reference points *A* and *B* to be seen. The reference points and the specimen outline (optional) are then drawn in. The reference triangle *ABC* is constructed to locate the position of *C* relative to points *A* and *B* and to fix the orientation of the peel (text-fig. 1G). As the reference points *A* and *B* are incorporated into the peel from the block surface the base-line *AB* must represent a standard reference through successive peels. Therefore, changes in the relative position of features of the sectioned specimen, both with regard to each other and to the reference points, can be ascertained by the changing values of $\angle ACB$.

TEXT-FIG. 1A–D. Graphical reconstruction of a skewed grid based on a cube whose dimensions are 40 mm rotated and tilted through 25°. A, top view after rotation. B, front view of rotated block. C, lateral view of rotated block after tilting. D, observer view of rotated and tilted block. E, F, plot of hypothetical data on rotation and tilt grids to show the high degree of distortion, left and right of the long axis, produced in a reconstruction, E, using unmodified *x* co-ordinates, compared with a reconstruction, F, using skewed *x* co-ordinates. G, plot of preliminary (× 10, linear) and ultimate (× 45, linear) data on to a squared grid to show the establishment of the reference triangle. H, reconstruction of part of an early juvenile *Zeilleria leckenbyi* (Dav.) based on a plot of 'cleared' (× 45) data from five serial cellulose acetate peels obtained from a transversely sectioned shell, showing the form of the posterior part of the frenuliform (bilacunar, Richardson 1975) loop.



α ≡ skew of z,x plane
β ≡ skew of y axis
γ ≡ skew of x,y plane = α + β
A
B
C
D
tilt axis
rotation axis
z
x
y
θ
A° B° D° C°
P° Q° S° R°
E
F
B′ C′ A′ D′ Q′ R′ P′ S′
φ
=D″S″
B″ C″ A″ D″ Q″ R″ P″ S″
G
H
X
Z
Z coordinates
X coordinates
y intercepts
upper face ABCD
lower face PQRS
after rotation θ and tilt φ
A″B″C″ etc.

Superimposition of microprojected structures at high magnification in which the reference points are not visible requires that the true position of A and B relative to the field of view be known.

After the initial procedure described above, the peel is microprojected at the magnification required e.g. × 250, with care being taken not to disturb the specimen's orientation. The microprojected image will be superimposed on the reference axes already constructed on the grid, with the same orientation relative to the reference triangle ABC as at × 10, thus locating the points A and B relative to the enlarged structure but now within the field of view. By recording the z, x co-ordinates 'cleared' data may be transferred to an appropriately skewed grid (text-fig. 1H). Traces of subsequent peels may be accurately superimposed by following the procedure described and then superimposing the skewed grid traces, using the constant base orientation defined by the reference axes (text-fig. 1H). As the reference points are fixed, this technique eliminates the problem of ensuring a constant orientation of the grid relative to the specimen, for successive peel traces.

The skewed reconstruction grid. The skewed grid can be constructed graphically (text-fig. 1A–D). A disadvantage is that it is a laborious process which must be repeated (Tipper 1976) each time the angle of rotation and/or tilt is changed. Ideally, what is required is a rotation and tilt formula which will enable skewed grids, accurate in geometric perspective, to be constructed for any angle of rotation at any angle of tilt of the specimen. Fortunately, such a formula is not difficult to derive. For any model, the amount of skew (α, text-fig. 1D) of the z, x (peel trace plane) co-ordinates may be expressed as $\tan \alpha = \cot \theta / \sin \varphi$ and the amount of skew (β, text-fig. 1D) of the y (trace superimposition) axis relative to the z, x plane, may be expressed as $\tan \beta = \tan \theta / \sin \varphi$ where θ represents the angle of rotation and φ represents the angle of tilt required in the reconstruction. The appropriate amount of foreshortening of the x, y, and z axes may be calculated as follows:

$$x \text{ axis} \equiv \mathrm{P''S''} = \sqrt{\{(\mathrm{AD} \sin \theta \sin \varphi)^2 + (\mathrm{AD} \cos \theta)^2\}}$$
$$y \text{ axis} \equiv \mathrm{S''R''} = \sqrt{\{\mathrm{DC} \sin \theta \cos \varphi)^2 + (\mathrm{DC} \sin \theta)^2\}}$$
$$z \text{ axis} \equiv \mathrm{D''S''} = \mathrm{D'S'} \cos \varphi.$$

Obviously, the initial length of the y axis will be scaled according to the section interval × linear magnification of the microprojected image. The appropriate reconstruction intercepts for y may be calculated using $\mathrm{S''R''}/n$ where $n \equiv$ the number of peels taken from the specimen. For superimposition of horizontal sections, the peel data will be transferred to an x, y grid in which the amount of skew (γ, text-fig. 1D) will be $\gamma = \alpha + \beta$ and the superimposition intercepts will be $\mathrm{D''S''}/n$.

Discussion. Where sufficiently sophisticated computer facilities are available the z, x co-ordinates of each rectangular peel trace can be recorded using a digitizer. This data can then be fed into a computer programmed for 'computerized modeling' (Tipper 1976). Graph plotting facilities would enable a skewed, three-dimensional image to be reconstructed.

A major advantage of the technique is that the x co-ordinates for successive values of z can also be plotted on an x, y (skew γ) grid thereby enabling horizontal reconstructions (Baker 1972, text-fig. 5) to be obtained from transversely sectioned material. Conversely, plotting the x co-ordinates for successive values of y on a z, x (skew α) grid enables transverse reconstructions to be obtained from horizontally sectioned material. Similarly, plotting the z co-ordinates for successive values of x on a z, y (skew β) grid enables longitudinal reconstructions to be obtained. Shading of the reconstruction to enhance the three-dimensional effect is advisable. This may be achieved by line shading or the use of stipple in the manner described by Isham (1963).

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